Water Resources Research Center
Annual Technical Report
FY 2017

Introduction

As Arizona's designated state water resources research institute, established under the 1964 Federal Water Resources Research Act, the University of Arizona Water Resources Research Center (WRRC) administers research grant programs and engages in information transfer activities that produce publications, website content, presentations, conferences and other public events. The WRRC is a research and Extension unit of the College of Agriculture and Life Sciences and is recognized statewide as a reliable source for water resources research and information transfer. Its mission is to "tackle key water policy and management issues, empower informed decision-making, and enrich understanding through engagement, education, and applied research." It accomplishes its mission by assisting communities in water management and policy; educating teachers, students and the public about water; and conducting applied research on state and regional water issues.

The WRRC's research programs address topics such as planning assistance for local communities, environmental water needs, managed aquifer recharge, transboundary aquifer assessment, and groundwater governance. The Information Transfer program translates this and other relevant research for use by water managers, other water professionals, policy makers, students and the public through outreach publications and presentations, engagement events, and communication media. The WRRC's research, education and outreach goals require collaborations and cooperative arrangements, and the WRRC builds partnerships inside and outside the university. Water, Environmental and Energy Solutions (WEES), a UA program funded by the Technology and Research Initiative Fund (TRIF), and Arizona Project WET (Water Education for Teachers) are key partners. The WRRC is the administrative home for WEES and Arizona Project WET, a program initiated at the WRRC in 1991 that is now Arizona's premier water education program. In addition the WRRC is closely linked with Arizona Cooperative Extension.

Research Program Introduction

The University of Arizona WRRC supports water resources research in Arizona with small research grants through the WRRA, Section 104(b) research grant program. The call for proposals encourages Investigators at the three state universities in Arizona to apply for these grants. For the past two years the call has focused on student research and requires that the student be listed as a co-Principal Investigatory. This change has resulted in increased participation without sacrificing the quality of the research. The WRRC typically selects two to four research projects for funding per year. Selected projects have addressed water research that contributes to resolving water resource issues across the state. Selection criteria include importance, potential impact, technical merit, and feasibility, as well as provision for student education and information transfer to research users.

A wide range of projects has been funded over the years, emphasizing the mandated program goals of improving water supply reliability and quality, exploring new ideas to address water problems, and expanding understanding of water and water-related phenomena. For the 2017-2018 cycle (March 1, 2016-February 28, 2017), the Technical Review Committee, made up of water resources experts from academe, agencies, utilities, and consultants, met on December 2, 2016 and evaluated the seven proposals received. For the 2017-18 grant cycle, the WRRC selected two research projects for funding:

• Impact of projected climate changes on mountain-block recharge processes, Principal Investigator: Thomas Meixner and Graduate Student: Ravindra Dwivedi, University of Arizona

• Might recycled wastewater solve the rising problem of toxin-producing algae? Principal Investigator: Kevin Fitzsimmons and Graduate Student: Robert Lynch, University of Arizona.

The proposed research was deemed by the Technical Review Committee to meet the high standards for significance and technical merit used in previous proposal reviews. Reports on these research projects are included in this report.

On December 8, 2017, the Technical Review Committee met to evaluate nine proposals for the 2018-2019 funding cycle. Two projects were recommended for funding:

• Microplastic Contamination in the Lower Santa Cruz River, Principal Investigators: Michael Bogan, David Quanrud, Student Co-Investigator: Drew Eppehimer, University of Arizona

• Using Fresh Water Algae to Remove Lead from Water, Principal Investigator: Robert Root, Student Co-Investigator: Amanda Minke, University of Arizona

Grants from the nationally competitive grants program (104(g)) awarded to Arizona investigators are administered by the WRRC, which is responsible for submitting the proposals from Arizona. The new preproposal process added processing preproposals and providing preproposal reviews to this responsibility. In 2017, Arizona submitted seven preproposals for 104(g) grants. No Arizona 104g projects were funded in 2017.

Transboundary Aquifer Assessment Program (TAAP): Arizona Water Resources Research Center Effort

Basic Information

Title:	Transboundary Aquifer Assessment Program (TAAP): Arizona Water Resources Research Center Effort
Project Number:	2016AZ584S
USGS Grant Number:	
Sponsoring Agency:	U.S. Geological Survey
Start Date:	9/1/2016
End Date:	8/1/2017
Funding Source:	104S
Congressional District:	AZ003
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Groundwater, Law, Institutions, and Policy, Models
Descriptors:	None
Principal Investigators:	Sharon B. Megdal

Publication

1. Callegary, J.B., Minjárez Sosa, I., Tapia Villaseñor, E.M., dos Santos, P., Monreal Saavedra, R., Grijalva Noriega, F.J., Huth, A.K., Gray, F., Scott, C.A., Megdal, S.B., Oroz Ramos, L.A., Rangel Medina, M., Leenhouts, J.M., (2016). Binational Study of the Transboundary San Pedro Aquifer. International Boundary and Water Commission, 170 p

Progress Report

In 2016, the Transboundary Aquifer Assessment Program (TAAP) for the San Pedro and Santa Cruz binational aquifers (specified as priority aquifers in 2006 by Public Law 109-448) continued its efforts in September with new funding. Activities focused on three tasks: 1) assist TAAP partners in completing the Santa Cruz Aquifer Report; 2) organize stakeholder workshops; and 3) characterize climate change impacts in the Santa Cruz River Basin. A summary for the *Binational Study of the Transboundary San Pedro Aquifer*, along with the officially and binationally-approved version of the Study, are forming the basis of stakeholder workshops. Characterization of precipitation pattern impacts will result in: high-resolution regional climate projections; establishment of a study area for hydrology projections in the Santa Cruz River Aquifer in Mexico and a survey of existing hydrologic models for the area; and a report on climate change assessment methodology and results. The effort follows methodology used by the WRRC and its partners through a previous NOAA-funded project. The International Boundary and Water Commission hosted a binational cooperation meeting in El Paso, TX in September to discuss current and future TAAP activities. Future activities include continued cooperation between the University of Arizona, USGS, the University of Sonora, and CONAGUA. The Binational Study of the Transboundary San Pedro Aquifer was officially approved by the U.S. and Mexican sections of the International Boundary and Water Commission. This first-ever binational aquifer assessment report underwent peer review and was prepared simultaneously in English and Spanish.

Impact of projected climate changes on mountain-block recharge processes

Basic Information

Title:	Impact of projected climate changes on mountain-block recharge processes
Project Number:	2017AZ570B
Start Date:	3/1/2017
End Date:	4/30/2018
Funding Source:	104B
Congressional District:	AZ-003
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Water Quantity, Water Quality, Groundwater
Descriptors:	None
Principal Investigators:	Thomas Meixner, Jennifer McIntosh, Ravindra Dwivedi, Paul Andrew Ferre

Publications

1. Dwivedi, R., T. Meixner, J. McIntosh, P. A. T. Ferré, C. J. Eastoe, G.-Y. Niu, R. L. Minor, G. Barron-Gafford, and J. Chorover (In review), Hydrologic functioning of the deep Critical Zone and contributions to streamflow in a high elevation catchment: testing of multiple conceptual models, Hydrological Processes.
2. Ravindra Dwivedi, T. M., J. McIntosh, P. A. "Ty" Ferre, C. Eastoe, C. Castro, W. W. Wright, G. -Y. Niu, R. Minor, J. Knowles, Greg A. Barron-Gafford, N. Abramson, B. Mitra, M. Stanley, and J. Chorover (in preparation), Examination of fractal behavior of various water balance components and hydrologic response functions for a mountainous sub-humid catchment, Water Resources Research.
3. Dwivedi,Ravindra, Thomas Meixner, Jennifer C. McIntosh, P. A. "Ty" Ferré, Christopher J. Eastoe, Rebecca L. Minor, Greg A. Barron-Gafford, and Jon Chorover, Hydrologic functioning of the deep Critical Zone and contributions to streamflow in a high elevation catchment: testing of multiple conceptual models (Poster ID: H41C-1449), AGU Fall meeting at New Orleans, LA, December 11-15, 2017.

Impact of projected climate changes on mountain-block recharge processes

Problem statement

Mountains are dominant areas of recharge to adjacent alluvial basins, which contain important groundwater resources for populations in arid and semi-arid regions (*Viviroli et al.*, 2007), e.g., southeastern Arizona (*Anderson*, 1972). For example, **66.5%** of Arizona can be classified as mountainous (*Figure 1A*); these areas receive a significant amount of precipitation, both rain and snow, as compared to the nearby lowland regions (*Cunningham et al.*, 1998). Yet, little is known about natural recharge processes or the hydrologic functioning of mountain systems, such as relative contribution of mountain-block recharge (deep flow paths) as compared to mountain front recharge (shallow flow paths) towards streamflow sustainability (focus of this study), which can be mostly attributed to: (a) the use of only short time-scale tracers such as stable water isotopes (*Ajami et al.*, 2011; *Heidbüchel et al.*, 2013) and (b) in general observational scarcity due to extreme topographic and climate gradients (*Bales et al., 2006; Manning and Solomon, 2005*). This limited understanding of hydrologic functioning of mountain systems limits our ability to assess how resilient or vulnerable water and/or ecological services provided by these systems will be to climate change (e.g., deep flow paths are likely to be less affected by climate change as compared to shorter flow paths). Therefore, the main goal of this research is to provide a better understanding of mountain system recharge processes and how such processes may be altered by climate change.

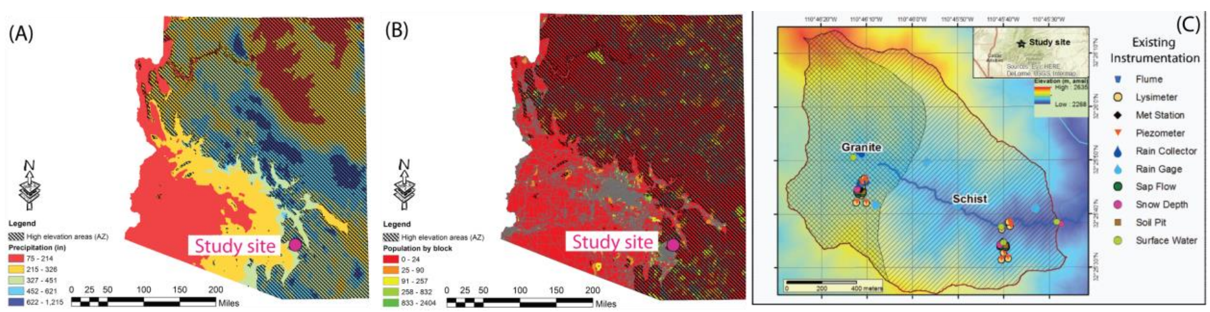

Figure 1.Spatial distribution of precipitation (high precipitation: blue and low precipitation: red) and high elevation (elevation higher than 1000 m, following Kohler and Marselli, 2009, definition) zones (shown by a hatch pattern) in Arizona (A), population by block in Arizona (Data source: United States Census Bureau, 2016) and high elevation zones (shown by a hatch pattern) (B), and existing instrumentation at our field site (C). Note, (i) our study site in (A) and (B) is shown by purple circle and (ii) the precipitation and elevation data for (A) and (B) are obtained from PRISM Climate group (Oregon State University) and the data for (C) are provided by Mr. Matej Durcik at the University of Arizona.

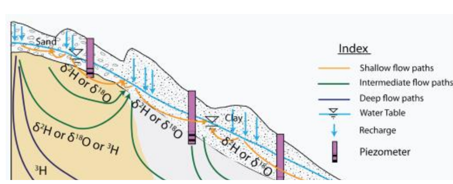

Figure 2.The proposed (at the time of proposal submission) conceptual model of our field site.

Research objectives

This study plans to address the following key science questions related to high elevation mountainous catchments: (i) What proportion of groundwater discharges into high elevation streams versus infiltrates to subsequently become mountain-block recharge in mountainous catchments, such as Marshall Gulch (MGC) located in the Santa Catalina Mountains (*Figure 1 C* & *Figure 2*), Tucson, Arizona? (ii) What is the inferred transit time distribution, and thus contribution of various subsurface flow paths to the mountainous streamflow when multiple tracers such as stable water isotopes and tritium are used for inferring that distribution? A successful assessment of our science questions will lead to an improved understanding of recharge processes and how catchments store water and discharge it with time, i.e., streamflow sustainability of high elevation mountainous catchments. The results will inform water management decisions (e.g., a better estimate of groundwater replenishment rate in lowlands through mountain systems will result in an improved recharge boundary condition in any regional- and/or local-scale groundwater flow or reactive transport models) for the state of Arizona where more than 50% of the state is covered by mountainous regions with an approximate population of 825,985 (*Figure 1B*). Furthermore, our findings will be relevant to other high elevation mountainous areas regionally and globally where fractured-bedrock aquifers may play a significant role for local or regional streamflow sustainability.

2.0 Study Site and Method Description

2.1 Study site and data used

This study focuses on the Marshall Gulch catchment (MGC), a high elevation mountainous catchment within the Santa Catalina Mountains Critical Zone Observatory (SCM-CZO), near Tucson, Arizona in the southwestern United States (Figure 1C). The catchment, which is part of the larger Sabino Creek watershed, has a total drainage area of 1.55 km^2 and ranges in altitude from 2268 m to 2635 m above mean sea level. The mean topographic slope is 23.64^o. Soil depth within MGC ranges from 0 to 1.5m [*Pelletier and Rasmussen*, 2009] and the soils are mostly sandy loam [*Holleran*, 2013]. The two dominant bedrock types (Figure 1C) are peraluminous granite of the Eocene Wilderness Granite Suite, mostly in the upper MGC, and metasedimentary rocks (schist) of the Proterozoic Apache Group and Troy Quartzite, mostly in the lower MGC [*Dickinson et al.*, 2002]. The vegetation at the site is mostly Madrean upper montane conifer-oak forest and Rocky Mountain aspen forest at high elevations to Madrean pine-oak woodland at lower elevations (Data source: *NatureServe* [2004]). The study site is located in a wilderness area where deep drilling is prohibited (the existing instrumentation is shown in Figure 1C). Therefore, no wells other than piezometers less than 1.5 m deep are available for sampling groundwater and most of the existing instrumentation is done for Granite and Schist subcatchments.

Our analysis is based on long-term observations of solute chemistry in stream water, precipitation and soil water between 2011 and early 2017, and a few short-term observations (in 2016 and 2017) of solute chemistry in springs and tritium concentrations in spring, soil, and stream waters. Furthermore, hydrological observations (precipitation, streamflow and mean air temperature, the latter as a surrogate for snowmelt behavior) from year 2008 through 2016 (i.e., water year 2009-2016) are used. A synthesis of all the available hydrological data is provided in Appendix A. All stream, soil water and precipitation chemistry, precipitation, streamflow, and groundwater depth data are publicly available on the SCM-CZO website (http://criticalzone.org/catalina-jemez/data/datasets/). Our seasonal divisions are defined as: (a)

Winter: October 1 through May 20, (b) Dry: May 21 through June 30, and (c) Summer monsoon: July 1 through September 30. As the mean daily air temperature is, in general, higher than the freezing point temperature for water (Figure A1 in Appendix A) at MGC, the winter season includes the early winter and late winter, i.e., snowmelt, seasons.

2.2 Estimating Tritium (^3H) model ages

For estimating ^3H model ages, water samples were collected in 1L HDPE bottles, during different seasons, and combined with previous data from the study area [*Ajami et al.*, 2011; *Cunningham et al.*, 1998]. Tritium was analyzed in the University of Arizona Environmental Isotope Laboratory (EIL). The estimation of ^3H model ages (t_{3H}) depends on the ^3H half-life ($t_{1/2}$), initial ^3H concentration (C_o) and concentration at the sampling time [$C_{(t)}$] (Equation 1). For $t_{1/2}$ we used a value of 12.32 years [*Lucas and Unterweger*, 2000]. The sample set includes three samples each for soil, Huntsman spring and stream waters and one sample each for the Pidgeon spring and Mt. Lemmon water district (MLWD) well for a Winter season (October 1 through May 20); one sample each for Huntsman spring and stream waters for a Dry season (May 21 through June 30); and one sample for soil water and two samples for stream water and three samples for Huntsman spring water for a Summer monsoon (July 1 through September 30) season (Table 1 below). This set of data led to three potential values of C(t) in terms of mean concentration (μ)-its one standard deviation (σ), μ, μ+σ. For C_o, an initial concentration of: (i) 4.1±0.5 TU was used for soil water samples that were expected to sample shorter flow paths (more details are provided in *Dwivedi et al.*, In review); and (ii) 6.3 TU±0.8 TU was used for spring and stream waters that were affected by contributions from deep flow paths.

$$t_{3H} = \frac{t_{1/2}}{ln(2)} ln(\frac{C_o}{C(t)}) \qquad (1)$$

Table 1. Tabular presentation of the 3H model ages (μ: mean age, σ: standard deviation) for soil water, spring waters (Huntsman and Pidgeon Springs), well water (Mount Lemmon water district well) and Stream water for the field site for various sampling events. Note, (i) a blank cell in the table represents extreme dry conditions when no water sample could be collected, and (ii) winter season samples are shown in blue, dry season samples are shown in orange, and sample collected during a summer monsoon season are shown in red.

Location	Sampling Date	Raw ^3H value in Tritium Units (TU) (μ±σ)	Season	3H model ages (years)		Data source	Comments
				Average (to the nearest integer)	Standard deviation (up to two decimal figures)		

Soil Water	9/8/2016	4.5 (±0.46)	Summer	1	1.15	This work	
			Dry				
	5/5/2016, 2/9/2017 and 4/27/2017	3.5 (±0.34), 3.4 (±0.29), and 3.6 (±0.25)	Winter	3	2.25	This work	
Huntsman Spring Water	7/15/1995, 9/2/2016, and 9/7/2017	6.5 (±0.7), 4.9 (±0.14), and 3.7 (±0.22)	Summer	6	3.51	This work and *Cunningham et al.* [1998]	It is called Huntsman spring in *Cunningham et al.* [1998]. Also, the maximum standard deviation as mentioned in *Cunningham et al.* [1998], is used.
	6/15/2009	4.4 (±0.23)	Dry	6	2.22	*Ajami et al.* [2011]	The max standard deviation =0.23 based on our data is applied here for min and max values.
	4/28/2016, 2/2/2017 and 4/27/2017	2.7 (±0.23), 2.7 (±0.21), and 2.3 (±0.23)	Winter	16	2.75	This work	

Stream water	9/2/2016 and 9/7/2017	4.1 (±0.27) and 2.8 (±0.2)	Summer	11	4.15	This work	
	6/15/2009	3.6 (±0.35),	Dry	10	2.55	*Ajami et al.* [2011]	
	4/28/2016, 2/2/2017 and 4/27/2017	2.6 (±0.35), 3.0 (±0.22), and 3.1 (±0.29)	Winter	14	2.88	This work	
Pidgeon Spring	10/20/2017	3.2 (±0.32)	Winter	12	2.58	This work	
Mt. Lemmon water District (MLWD) well	10/20/2017	3.1 (±0.22)	Winter	13	2.34	This work	

2.3 End-member mixing analysis (EMMA)

Based on the EMMA method of *Hooper* [2003], as modified by *Barthold et al.* [2011], we included 37 of 42 measured tracers in our principal component analysis (PCA). The full list of tracers includes dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), F, Cl, SO_4, Na, Mg, Al, Si, K, Ca, Cr, Fe, Co, Ni, Cu, Zn, Y, Cd, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, δ^2H, Sr, Mo, Ba, As, Se, Sn, and Sb. Stable O and H isotope data for precipitation and streamflow are available from 2006 through 2010, while weekly to bi-weekly stream chemistry observations started in 2009. To avoid issues related to data gaps, we accepted tracers with at least 90% data availability (shown by the red line in Figure 3 below), and consequently excluded Cd, Pb, δ^2H, Sn, and Sb.

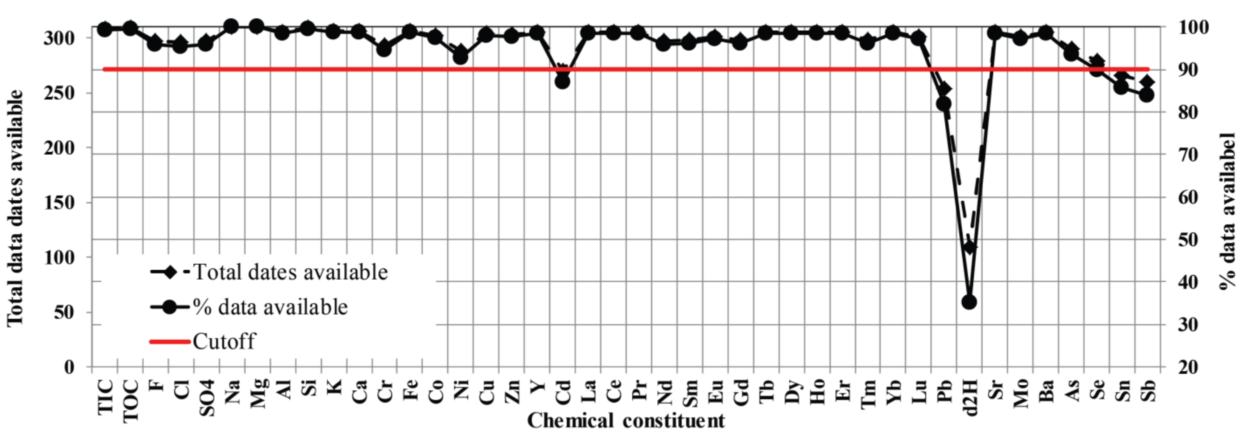

Figure 3. Total number of dates with available concentration data for various chemical constituents (shown along the left y-axis) and percentage number of available data dates for the same constituents (shown along the right y-axis) for the Marshall Gulch stream water chemistry. The red line shows the cutoff (based on 90% data available for any chemical constituent) for data used in the EMMA. PCA part of the EMMA uses all these 37 tracers.

In EMMA, with the compiled stream chemistry dataset several stream chemistry diagnostic plots are created, following *Hooper* [2003], for identifying the conservative solutes and the dimension of the mixing space required for explaining the observed stream water composition. Note that the main simplifying assumptions involved in the EMMA approach were: (a) different water stores within the CZ structure are geochemically distinct with negligible temporal variability and (b) a mixture of various water types is conservative. The EMMA starts with creating bivariate solute-solute plots, and then it moves on to creating residuals vs. observed concentration plots. Finally, plots for cumulative variance explained vs. number of eigen vectors, as well as residual root mean square error vs. number of eigen vectors (or principal components) retained, were created to evaluate the required dimensionality of the mixing space using the following three guidelines:

(G1) Rule of one [*Jöreskog et al.*, 1976], which suggests that all eigen values higher than 1 should be retained [*Hooper*, 2003],

(G2) explain 80-90% variability, which suggests that one should retain as many eigen vectors as needed to explain approximately 80-90% of the variability of the observed dataset [*Christophersen and Hooper*, 1992], and

(G3) retain a *minimum* number of eigen vectors such that the pattern between residuals and observed concentrations for a conservative tracer is random [*Hooper*, 2003].

2.4 Estimating outliers for any N-dimensional mixing space and contributions from each endmember towards streamflow

For estimating total number of outliers in any N-dimensional mixing space and for estimating the contribution of each end-member towards streamflow, we followed these steps:

STEP 1. Use a modified version of Equation (1) from *Christophersen and Hooper* [1992] for estimating the fractional contribution of each endmember for each stream water composition. The modification to Equation (1) from *Christophersen and Hooper* [1992] is to ensure conservation of mass or total streamflow.

STEP 2. If any fractional contribution is negative for any streamflow composition, then that composition is considered as an outlier to the N-dimensional mixing space.

STEP 3. An outlier for the mixing space is reprojected back on the N-dimensional mixing space by substituting the negative fractional contribution from any endmember as zero and then redistributing the negative fractions to the remaining positive fractions from the other endmembers with the conditions that sum of all fractions from all endmembers is one.

2.5 Baseflow recession analysis for estimating seasonal maximum dynamic CZ storage

Our baseflow recession analysis follows the methods of *Arciniega-Esparza et al.* [2016] and *Troch et al.* [in review]. In the baseflow recession analysis, one-parameter (*a*, a value of 0.925) is used for this parameter [*Troch et al.*, 2017], recursive filter (see Equation 2 below) is used for separating baseflow (B_t for any timestep t), and stormflow (S_t)-defined as Q_t-B_t - from daily streamflow observations at any time (Q_t). Furthermore, following the method described in *Troch et al.* [2017] the final baseflow time-series for the whole period-of-record was used for determining the reservoir constant *K*. Once the reservoir constant *K* was known, the maximum daily baseflow (B_{max}) was estimated for various seasons such as Winter, Dry and Summer monsoon separately, considering the whole period of record. With the B_{max} for each season and *K* for the whole period-of-record, the maximum seasonal storage was estimated as the product of B_{max} and *K*.

$$B_t = aB_{t-1} + (\frac{1-a}{2})(Q_t + Q_{t-1}) \qquad (2)$$

Principal findings and significance

The main findings and significance of those findings towards our overarching research objectives will be presented in the final version of this report.

Appendix A. Precipitation, streamflow, daily air temperature pattern at MGC

The Marshall Gulch catchment is characterized by a bimodal pattern for both precipitation and streamflow (Figure A1). The climate for our site is characterized as a sub-humid climate with mean annual precipitation of 800 mm [*Heidbüchel et al.*, 2013], however, total annual precipitation is 525 mm from water year 2009 through 2016. Of the total annual precipitation of 525 mm, ~44 % of it falls during October 1 through May 20 (i.e., Winter season), ~53 % falls during July through September months (i.e., Summer monsoon season), and a small percentage ~3% falls during May 21 through June 31 (i.e., Dry season) of a water year. Total average annual streamflow for the field site is 202 mm from water year 2009 through 2016, and it represents ~38% of the total annual precipitation. There are two peaks in the streamflow time-series, with one occurring during late Winter and the other occurring during the early Summer monsoon season. Additionally, the streamflow behavior of the field site is ephemeral with ~12 % probability of less than ~10^{-6} mm/day streamflow (including no streamflow) as per the period-of-record flow duration curve, and ~ 23 % probability of <~10^{-6} mm/day streamflow as per the median annual flow duration curve. Because of the ephemeral streamflow, there are no data when conditions at the field site are extremely dry. The hypsometric curve for the field site is a standard S-shape curve. Average annual temperature for the field site is 10.40^{o}C and it ranges between a minimum of 1.5^{o}C to a maximum of 19.9^{o}C for a water year (Figure A1).

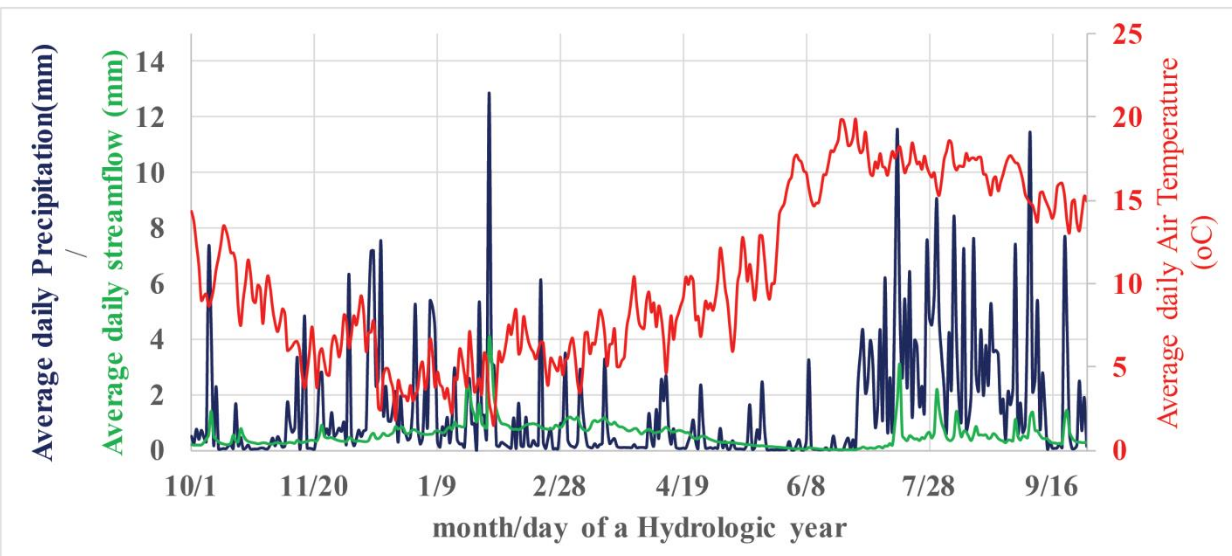

Figure A1. Mean daily historical pattern of Precipitation (in blue), streamflow (in green) and air temperature (in red) for MGC. The air temperature is measured at 2-m height above ground at the nearest meteorological station, i.e., Mt. Bigelow site, Tucson, Arizona.

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Might Recycled Wastewater Solve the Rising Problem of Toxin-Producing Algae?

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1. Lynch, R.A. 2018. Might Recycled Wastewater Solve the Problem of Toxin-Producing Algae? M.S. Dissertation, Department of Soil, Water and Environmental Science, College of Agriculture and Life Sciences, University of Arizona, Tucson, AZ, 70 pp.
2. McLain, J.E., R.A. Lynch, and K. Fitzsimmons. In preparation, Might Recycled Wastewater Solve the Problem of Toxin-Producing Algae? Environmental Research (special issue on water reuse).
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MIGHT RECYCLED WASTEWATER SOLVE THE PROBLEM OF TOXIN-PRODUCING ALGAE?

Problem and Research Objectives. Cyanobacteria, or blue-green algae, is a phytoplankton phylum found in surface water bodies worldwide. For decades, blue-green algae have caused severe aesthetic water quality problems and induced water deoxygenation, leading to fish kills and other detrimental outcomes. Furthermore, some cyanobacterial genera, most notably several *Microcystis* species, are known to produce neurotoxic peptides known as microcystins. Such toxin production is of critical and increasing public health concern, as neurotoxic and/or hepatotoxic cyanobacterial algal blooms in freshwater lakes and streams have been implicated in human and animal sickness, and even death, in recent years [1, 2]. Toxic algal blooms during summer months have been particularly prominent in news across the U.S., sickening recreational swimmers in several states [3-5] and leading to public health advisories nationwide, including in Arizona [6, 7]. Temporal enhancement of toxic algal blooms suggests that environmental triggers may be inducing cyanobacterial production of microcystins. However, such environmental triggers are currently poorly understood. Studies have correlated increased toxin production to enhanced temperature, nutrient concentrations, and light intensity [8-11], but research results examining microcystin toxin production in response to environmental stimuli have rarely been conclusive outside of the laboratory or over multiple seasons. Enhanced knowledge of the regulation of microcystin toxin biosynthesis may facilitate implementation of water management strategies to avoid environmental conditions that induce dangerous water quality conditions. If uncontrollable environmental factors are identified as the culprits inducing toxin production, knowledge of these factors would contribute to predictive models to forecast toxic algal blooms, expediting beach closures and protecting public health.

Project Objectives. This project implemented advanced molecular techniques (real-time quantitative PCR) to detect and quantify cyanobacterial genes (CYAN) and toxin synthesase genes (*mcy*) in sixteen (16) bulk water samples collected from recycled water retention ponds at the Sweetwater Wetlands (Tucson, Arizona) and groundwater-filled ponds at the Maricopa Agricultural Center (Maricopa, Arizona). In addition, water samples were assayed for the presence of toxins as well as physical and chemical parameters (heavy metals, pH, turbidity, temperature) known to influence cyanobacterial blooms and toxin production.

The specific objectives of this proposed work were:

- To perform a targeted biological and chemical analysis of sixteen (16) water samples (8 recycled, 8 groundwater) collected over one full summer, to enumerate CYAN and *mcy* gene markers, assess concentrations of a suite of heavy metals, and identify concentrations of microcystin toxins (MC-LR) in collected samples; this work was done under the hypothesis that *mcy* gene markers and microcystin concentrations would correlate with heavy metal concentrations and other environmental parameters.
- To generate a dataset to be used in application for significant funding.
- To supplement training in field collection and modern molecular analysis of environmental samples for one master's student for one summer.

Methodology. This study analyzed water quality in a recycled wastewater recharge basin at Sweetwater Wetlands (SW) and a groundwater-filled irrigation retention pond at the Maricopa

Figure 1. Sampling sites at the recycled water pond (Sweetwater Wetlands, left) and the groundwater-filled pond (MAC Irrigation Retention Pond, right). Yellow tacks indicate recycled water sampling locations, while green tacks indicate groundwater-filled sampling locations.

Agricultural Center (MAC; Figure 1). Water sample collections occurred monthly between May and September, 2017. Over the length of the project, a total of 24 water samples were collected from each pond, totaling 48 pond samples. Water was collected at the surface using a grab sampling technique and 1 L sterile Nalgene® plastic bottles. Samples were stored on ice during transport to the University of Arizona laboratory in Tucson, AZ.

Sample Analyses. Chemical and physical parameters measured in each water sample included temperature, turbidity, pH, and electrical conductivity. At time of field collection, temperature, turbidity, and conductivity measurements were obtained using a field thermometer (Fisher Scientific, Pittsburgh, PA), Milwaukee/Martini-Instruments Turbidity Meter (MI 415) (Milwaukee Instruments, Inc., Rocky Mount, NC), and a Traceable® Conductivity Meter (VWR International, LLC, Radnor, PA) respectively. At the University of Arizona laboratory, pH values were obtained with a Corning pH Meter 430 (Corning Inc., Corning, NY).

Table 1: Metal isotopes analyzed by ALEC using ICP-MS.

Metal	**Abbreviation**	**Atomic Mass**
Beryllium	Be	9
Aluminum	Al	27
Vanadium	V	51
Chromium	Cr	52
Manganese	Mn	55
Iron	Fe	56
Cobalt	Co	59
Nickel	Ni	60
Copper	Cu	63
Zinc	Zn	66
Arsenic	As	75
Selenium	Se	78
Molybdenum	Mo	95
Silver	Ag	107
Cadmium	Cd	111
Tin	Sn	118
Antimony	Sb	121
Barium	Ba	137
Lead	Pb	208

Inorganic and Organic Methods. For inorganic (metals) analysis, a single pond sample was produced from each location on sampling dates by compositing the respective sub-samples and filtering 15 mL into a Metal Free Centrifuge Tube (VWR® International, LLC, Radnor, PA) via 0.45 µm Nylon Syringe Filters (VWR® International, LLC, Radnor, PA). The analyses for metals listed in Table 1 were performed by the Arizona Laboratory for Emerging

Contaminants (ALEC) at the University of Arizona using inductively-coupled plasma mass spectrometry (ICP-MS; Elan DRC II, Perkin Elmer). For organic analysis to quantify the presence of the microcystin toxins (MC-LR), 50 mL aliquots of each water sample were subjected to three freeze/thaw cycles of -80 °C and 37 °C to lyse cells and release total MC-LR into solution. Water samples were then filtered into sterile 50 mL conical tubes using 1.5 µm Nylon Syringe Filters (Thermo-Scientific™, Rockwood, TN). The analysis for MC-LR was performed at ALEC using liquid chromatography-tandem mass spectrometry (LC-MSMS; Dionex Ultimate 3000, Dionex-Thermo). A stock solution of MC-LR (dilution series spanning 374 ppb to 3 ppt) was used as a positive control (Sigma-Aldrich Co., LLC, St. Louis, MO).

DNA Extraction and Purification. Bacteria were isolated by filtering each pond sample onto Whatman® 0.45 µm pore size membrane filters via a Millipore vacuum filtration system. Due to varying turbidity between individual samples, which could range from 0.5 Nephelometric Turbidity Units (NTU) to 890 NTU on any given day, between 75 mL and 500 mL of each water sample was filtered for downstream DNA extraction. Filters were stored in 15 mL conical vials at 4 ºC until extraction. Total DNA extraction from the filters was performed using a MOBio Laboratories, Inc. PowerBiofilm® DNA Isolation Kit (MOBio Laboratories, Inc., Carlsbad, CA) according to manufacturer instructions. DNA extracts were stored (-80 ºC) until further processing.

Molecular Methods. To quantify DNA markers corresponding to total cyanobacteria and toxic *Microcystis spp*., all DNA extracts were analyzed for cyanobacterial (*CYAN*) and toxin synthetase (*mcyD*) gene markers using quantitative polymerase chain reaction (qPCR). Quantitative standards (ranging from 300,000 to 3 markers per µL) for qPCR were created from PCR products of the target size (*CYAN* and *mcyD* gene markers were 267 bp and 297 bp respectively) [12]. For each water sample, two qPCR reactions were carried out to detect *CYAN* and *mcyD* gene markers using primers and probes listed in Table 2. All qPCR reactions were performed using an AB Applied Biosystems Step One™ Thermocycler (Life Technologies, Grand Island, NY) using MicroAmp™ Fast Optical 48-Well Reaction Plates (0.1 mL). Each 25 µL qPCR reaction was comprised of 8.5

Table 2: Primer and probe sequences used for qPCR.

Primer	Sequence (5'- 3')	Reference
CYAN 108F	ACGGGTGAGTAACRCGTRA	[13]
CYAN 377R	CCATGGGCGGAAAATTCCCC	[13]
mcyDF	GGTTCGCCTGGTCAAAGTAA	[12]
mcyDR	CCTCGCTAAAGAAGGGTTGA	[12]
CYAN – Probe	(6FAM)CTCAGTCCCAGTGTGGCTGNTC(TAM)	[13]
mcyD - Probe	(6FAM)ATGCTCTAATGCAGCAACGGCAAA(TAM)	[12]

µL Nuclease Free Water, 12.5 µL BIO-RAD SsoAdvanced™ Universal Probes Supermix, 400 nM Forward Primer (Sigma-Aldrich Co., LLC, St. Louis, MO) (Table 4), 400 nM Reverse Primer (Sigma-Aldrich Co., LLC, St. Louis, MO) (Table 4), 0.1 mM probe (Bio-Rad Laboratories, Inc., Hercules, CA) (Table 4), and 1 µL of extracted DNA. Corresponding emission of fluorescence from a standard curve of serial log dilutions (300,000 to 3 markers per µL) allowed for quantification of unknown samples.

Data Analysis. Correlations and 2-Sample T-tests of statistical significance ($p \leq 0.05$) for molecular markers, MC-LR concentrations, physical and chemical water quality parameters, and metal concentrations were calculated by Minitab Release 14.20 Statistical Software (Minitab® Statistical Software, State College, PA).

Principal Findings.

Molecular (CYAN and mcyD). Molecular markers (*CYAN* and *mcyD*) were quantified over six months (Figures 2 and 3, respectively). Over the course of sampling, *CYAN* markers were slightly higher in the groundwater pond (MAC) than the recycled water pond (SW), averaging 1.06 x 10^{12} and 5.59 x 10^{11} markers 100 mL^{-1} respectively, but this difference was not significant (p = 0.158). *CYAN* markers at SW displayed an increasing trend between April and July compared to MAC, with a noted decrease occurring in September for both ponds (Figure 2).

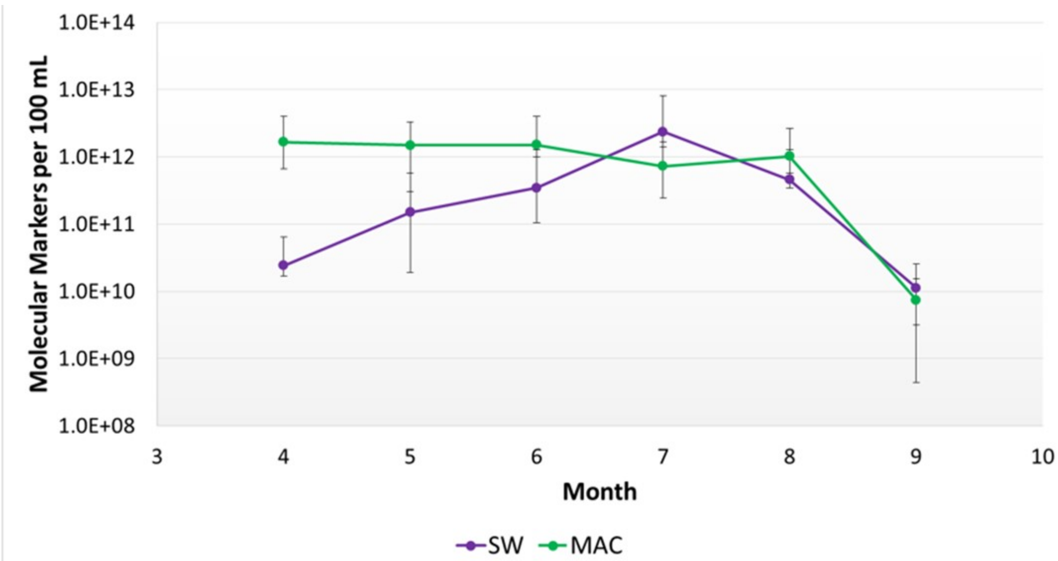

Figure 2. Average *CYAN* molecular markers per 100 mL measured in pond samples over 6 months. Error bars represent standard deviation of four pond measurements collected at each site on each sampling date.

Over the course of sampling, *mcyD* markers were always higher in MAC than in SW, averaging 2.44 x 10^7 and 1.66 x 10^3 100 mL^{-1} respectively over six months (t = -6.79; $p \leq 0.001$) (Figure 3). A spike in *mcyD* markers was observed during July and August at MAC, whereas *mcyD* markers were below detection limits in June and July at SW (Figure 3).

MC-LR. Though all 48 samples were analyzed for MC-LR, the toxin was detected only in waters collected from MAC during July and August, averaging 6.762 ± 0.021 and 6.643 ± 0.022 µg L^{-1} respectively (Table 3). Although the highest water temperatures in MAC occurred during July and August, MC-LR concentrations were negatively correlated with temperature (r = -0.795; p = 0.018).

Environmental and Chemical Parameters. Average levels of heavy metals in samples collected from MAC and SW are found in Table 4. Statistical analysis revealed higher concentrations of: V_{51} in MAC (t = -5.52; p = 0.003), Mn_{55} in SW (t = 2.64; p = 0.046), Fe_{56} in SW (t = 6.89; p = 0.001), As_{75} in MAC (t = -6.81; p = 0.001), and Se_{78} in MAC (t = -4.07; p = 0.010) than SW. Statistical analysis performed between each parameter listed in Table 4 with *CYAN* and *mcyD* molecular markers (Figures 2 and 3) revealed significant positive correlations between SW *CYAN* markers and metals: V_{51} (r = 0.901; p = 0.014), As_{75} (r = 0.882; p = 0.020), and Sb_{121} (r = 0.921; p = 0.009). *CYAN* markers in MAC revealed significant negative correlations with Zn_{66} (r = -0.868; p = 0.025), and Ba_{137} (r = -0.861; p = 0.028), while MAC *mcyD* markers revealed a significant negative correlation with Cr_{52} (r = -0.908; p = 0.012).

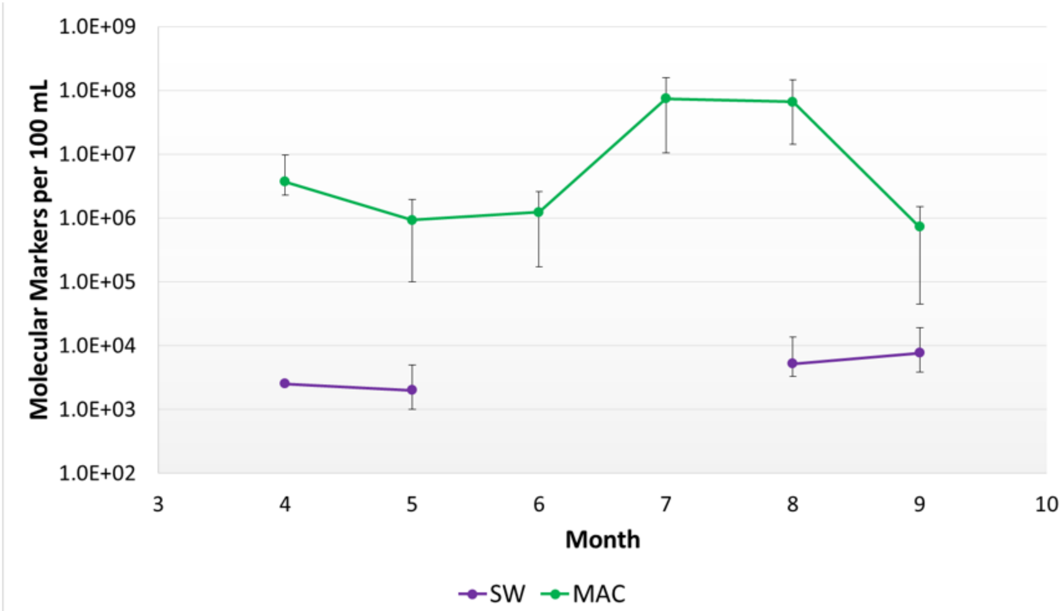

Figure 3. Average *mcyD* molecular markers per 100 mL measured in pond samples over 6 months. Error bars represent standard deviation of four pond measurements collected at each site on each sampling date.

Table 3 (below). Concentrations for MC-LR detected in MAC samples. Parentheses for average concentrations represent standard deviation. MC-LR levels in the remaining 40 water samples collected over six months were below limits of detection. **Table 4 (right).** Metal isotopes measured in SW and MAC. Values represent average of six monthly samples (standard deviation in parentheses).

Sample	MC-LR [μg L^{-1}]
MAC 4-1	6.794
MAC 4-2	6.752
MAC 4-3	6.749
MAC 4-4	6.753
MAC 5-1	6.631
MAC 5-2	6.642
MAC 5-3	6.673
MAC 5-4	6.624
MAC 4 AVG	**6.762 (0.021)**
MAC 5 AVG	**6.643 (0.022)**

Metal	SW [μg L^{-1}]	MAC [μg L^{-1}]
Be_{9}	0.02 (0.04)	0.01 (1.79)
Al_{27}	1.35 (0.71)	3.17 (1.79)
V_{51}	3.09 (2.55)	10.04 (2.43)
Cr_{52}	0.81 (0.45)	1.40 (0.57)
Mn_{55}	31.84 (28.90)	0.45 (0.39)
Fe_{56}	33.42 (10.30)	2.32 (1.92)
Co_{59}	1.21 (2.00)	0.69 (1.00)
Ni_{60}	2.15 (1.11)	1.07 (0.86)
Cu_{63}	0.37 (0.23)	0.86 (0.57)
Zn_{66}	9.16 (7.50)	3.19 (4.39)
As_{75}	4.22 (2.85)	13.56 (1.74)
Se_{78}	1.20 (0.61)	1.95 (0.49)
Mo_{95}	5.17 (2.85)	3.83 (0.66)
Ag_{107}	0.01 (0.00)	0.01 (0.00)
Cd_{111}	0.02 (0.01)	0.02 (0.01)
Sn_{118}	0.04 (0.02)	0.15 (0.30)
Sb_{121}	0.34 (0.18)	0.48 (0.29)
Ba_{137}	54.40 (27.64)	32.94 (9.98)
Pb_{208}	0.03 (0.03)	0.06 (0.07)

Physical and chemical parameters of water samples collected at SW and MAC are located in

Tables 5 and 6, respectively. Statistical analysis performed between each parameter listed in Tables 5 and 6 with *CYAN* and *mcyD* molecular markers in each pond revealed a negative correlation between *CYAN* markers in MAC and conductivity (C) (r = -0.847; p = 0.033). Average temperature and turbidity values were lower in SW compared to MAC, but their differences were not significant (p = 0.073 and p = 0.675 respectively). Increased pond temperatures were observed in SW between June and August, whereas water temperatures in MAC showed a slight increase during July and August. MAC showed significantly higher pH values compared to SW (t = 7.26; p = 0.000), but conductivity showed no significant difference (0.113).

Table 5 (top). Physical and chemical water parameters of SW over course of sampling. Each value represents an average of four measurements (standard deviation in parentheses). Turbidity measurement of 229.5 (440.4) at SW was largely influenced by a single collection at sampling site SW1 (890.00 NTU). This most likely due to a noticeable drop in water elevation at only site SW1 on that sampling date. **Table 6 (bottom).** Physical and chemical water parameters of MAC over course of sampling. Each value represents an average of four measurements (standard deviation in parentheses).

SW	T (°C)	T (NTU)	pH	C (mS)
4	21.5 (1.0)	10.2 (17.7)	7.4 (0.0)	0.94 (0.05)
5	22.3 (1.4)	4.6 (3.4)	7.4 (0.0)	1.25 (0.04)
6	29.7 (2.5)	229.5 (440.4)	7.9 (0.4)	1.23 (0.05)
7	30.3 (2.1)	10.6 (5.7)	8.4 (0.8)	1.15 (0.04)
8	28.6 (1.6)	16.7 (4.0)	7.6 (0.4)	1.13 (0.05)
9	22.4 (2.1)	21.3 (14.5)	7.5 (0.1)	1.10 (0.12)

MAC	T (°C)	T (NTU)	pH	C (mS)
4	25.5 (0.6)	40.8 (3.5)	10.2 (0.1)	1.13 (0.02)
5	28.8 (0.4)	34.2 (3.6)	9.1 (0.7)	1.07 (0.03)
6	28.2 (0.9)	35.3 (4.4)	9.8 (0.0)	1.12 (0.02)
7	29.9 (0.3)	38.0 (6.0)	9.3 (0.0)	1.13 (0.02)
8	30.7 (0.2)	23.6 (2.2)	9.3 (0.0)	1.13 (0.03)
9	23.1 (0.6)	27.4 (4.1)	9.3 (0.1)	1.78 (0.03)

Discussion of Major Findings. This study examined the molecular markers specific to *CYAN* and *mcyD* genes over the course of six months in a recycled water retention pond and a groundwater-filled irrigation retention pond. Levels of *CYAN* in both ponds shared similar orders of magnitude with each other, suggesting that the difference in water source did not negatively impact cyanobacteria presence. Microcystin synthetase genes, *mcyD*, were always detected in MAC, with levels reaching three to four orders of magnitude greater than in SW. Strong seasonal trends of both molecular markers were not observed, however, levels of *CYAN* increased slightly from April to July in SW, followed by a decrease of *CYAN* levels during August in both ponds.

Pond samples were analyzed to determine if presence of *mcyD* markers correlated to MC-LR production. MC-LR production was detected only in samples collected from MAC during July and August, with concentrations six times greater than the potable water limit of 1.0 µg L^{-1} recommended by the World Health Organization (WHO). Water temperatures in MAC reached their highest average during July and August (29.9 and 30.7 °C respectively), correlating significantly with MC-LR concentrations (r = -0.795; p = 0.018). This finding supports previous studies that showed microcystin production increases between 26 and 32 °C [14]. Although the difference in average water temperature between the two ponds was not significant, the absence of vegetation and shade at the MAC pond is the most likely reason for higher average water temperatures at MAC.

Although no significant correlation was observed between MC-LR concentrations and metals, *mcyD* levels in MAC showed a significant negative correlation with Cr_{52} that parallels a previous finding (r = -0.908; p = 0.012) [15]. Cr_{52} is known to negatively impact cyanobacteria by inhibiting photosynthesis, however, Cr_{52} was not significantly correlated with *CYAN* levels in either SW or MAC ($p = 0.843$, $p = 0.285$ respectively) [16]. Cr_{52} was on average higher in MAC than in SW (1.40 ± 0.57 vs 0.81 ± 0.45 ppb), but this difference was not significant ($p = 0.079$). Interestingly, Cr_{52} was lowest in MAC during July and August, falling to 0.68 and 0.76 ppb. This noted decrease of Cr_{52} in MAC coincided with MC-LR synthesis, suggesting that increased concentrations (although only slightly) of Cr_{52} in MAC that occurred during all other sampling dates inhibited MC-LR synthesis.

Iron is one of Earth's most abundant metals and has been shown to affect microcystin-production and growth rate of *Microcystis aeruginosa* [17]. Fe_{56} was significantly lower ($p = 0.001$) in MAC when compared to SW, but it was not significantly correlated with *mcyD* levels in MAC ($p = 0.780$) or SW ($p = 0.646$). Despite the insignificant correlations, lower concentrations of Fe_{56} in MAC may have contributed to MC-LR synthesis.

CYAN markers in SW were positively correlated with V_{51}, As_{75}, and Sb_{121}, indicating increased levels of *CYAN* with higher concentrations of those metals. *CYAN* levels in MAC however, were negatively correlated with Zn_{66} and Ba_{137}, indicating an inverse relationship. Some metals may elicit a toxic effect, however, depending on their oxidation-state and concentration, cyanobacteria may accumulate, detoxify, or metabolize metals [18].

Vanadium-containing nitrogenases are enzymes present in cyanobacteria necessary for nitrogen fixation, whereas arsenic and antimony have been associated with photosynthesis and growth rates [19]. Studies have shown high levels (10 mg L^{-1}) of As(III) to inhibit growth and photostem II (PSII) activity of *M. aeruginosa*, however, low concentrations (such as those detected in both ponds) of As(III) have no inhibitory effect [20]. Similar to As(III), Sb(V) has also been shown to have adverse effects on growth, pigment content, and PSII, however, low concentrations (≤ 5 mg L^{-1}) of Sb(V) can stimulate *M. aeruginosa* growth [16]. Zinc is known as essential to cyanobacteria which supports the correlation with *CYAN* levels in MAC [18]. SW contained slightly higher concentrations of Zn_{66}, however, the difference in Zn_{66} between ponds was not significant ($p = 0.131$).

Average water temperatures in SW were cooler than in MAC, but this difference was not significant ($p = 0.073$). Cooler water temperatures at SW could be attributed to wetlands' ability to moderate temperature extremes [21]. Higher average turbidity values at MAC may have fostered a positive feedback mechanism in which higher turbidity absorbs more sunlight and increases water temperature. Turbidity, as well as pH, is positively associated with algal growth, and higher average turbidity and pH in MAC suggests that algal concentrations may be greater than in SW. However, *CYAN* levels were similar in each pond.

Quantification of chlorophyll α, a pigment necessary for photosynthesis that is found in algae and cyanobacteria could be employed in future methodologies to measure photosynthetic activity. Photosynthetic activity removes dissolved CO_2 and thus raises pH. Qualitatively assessing how green the pond water is can be subjective, and will not provide the same level of confidence as chlorophyll α measurements. Quantitating chlorophyll α provides unbiased measurements that can be used for statistical analysis that lend support to observations such as significantly higher pH values in MAC.

Conclusions. The results of this study revealed significant differences in temperature, pH, select metals (including Fe_{56}), *mcyD* markers, and MC-LR biosynthesis between SW and MAC. The negative correlation between *mcyD* markers in MAC with Cr_{52} has been paralleled in a previous study, suggesting Cr_{52} may play a role in microcystin-production. However, microcystin-production is complex and may not be controlled by a single environmental variable, but most likely the simultaneous occurrence of many. It has been shown in previous studies that iron limitation may be a strong contributing factor for *mcyD* presence and MC-LR biosynthesis. Despite the insignificant correlation (p > 0.05) between *mcyD* levels or MC-LR toxin concentrations with Fe_{56}, lower levels of Fe_{56} in MAC may have contributed to microcystin-production. The differences in water quality parameters between SW and MAC did not contribute to differences in *CYAN* levels, however, the differences may have inhibited microcystin-production in SW.

Forecasting toxigenicity during algal blooms has been challenging for water professionals, and thus measures to prevent HABs have focused on reducing nutrient loading (N & P) which favors algal growth. Past studies have concentrated on the roles of N and P in relation to microcystin-production, however, the results of this study suggest metals (including but not limited to Cr_{52} and Fe_{56}) may play critical contributory roles. Recycled water ponds provide a unique opportunity for increased understanding of toxin-producing cyanobacteria. Culture-based studies are rarely reproducible in the field, however, the differences in water quality parameters and environmental characteristics of a recycled water pond and a groundwater-sourced pond could facilitate the development of predictive models to forecast toxic algal blooms.

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TAAP: University of Arizona Water Resources Research Center Effort

Basic Information

Title:	TAAP: University of Arizona Water Resources Research Center Effort
Project Number:	2017AZ587S
USGS Grant Number:	
Sponsoring Agency:	U.S. Geological Survey
Start Date:	9/5/2017
End Date:	9/4/2018
Funding Source:	104S
Congressional District:	AZ003
Research Category:	Not Applicable
Focus Categories:	Drought, Groundwater, Management and Planning
Descriptors:	None
Principal Investigators:	Sharon B. Megdal

Publications

1. Callegary, J.B., Megdal, S.B., Tapia-Villaseñor, E.M., Minjárez-Sosa, I., Petersen-Perlman, J.D., Monreal, R., Gray, F., and Grijalva-Noriega, F. (in review), Lessons learned from the assessment of the Mexico United States transboundary San Pedro and Santa Cruz aquifers, Journal of Hydrology: Regional Studies,Special Issue, Rivera, A. and Candela, L., eds.
2. Callegary, J.B., Minjárez Sosa, I., Tapia , E. M., dos Santos, P., Monreal Saavedra, R., Grijalva Noriega, F.J., Huth, A.K., Gray, F., Scott, C.A., Megdal, S.B., Oroz Ramos, L.A., Rangel Medina, M., Petersen-Perlman, J.D., Leenhouts, J.M. (in review). Binational Study of the Transboundary Santa Cruz Aquifer. International Boundary and Water Commission.
3. Megdal, S.B. (2017) The Cooperative Framework for the Transboundary Aquifer Assessment Program: A Model for Collaborative Transborder Studies, Arizona Water Resource, 25 (3), Summer Issue, https://wrrc.arizona.edu/public-policy-cooperative-framework-TAAP. Spanish version: https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/pub-pol-rev-spanish-summer-2017.pdf. Link and short abstract included on page 20 of September 2017 IWRA Newsletter.
4. Megdal, S.B. and Petersen-Perlman, J. (Accepted). Groundwater Governance and Assessment in a Transboundary Setting, in Grover, V.I. and Krantzberg, G. (Eds.), Lake Governance, CRC/Taylor and Francis, The Netherlands.
5. Petersen-Perlman, J.D., T.R. Albrecht, S.B. Megdal, & R.G. Varady. (In preparation_ Advancements in Science through Transboundary Groundwater Cooperation: The Transboundary Aquifer Assessment Program in the Mexico-United States Border Region. Environmental Research Letters (Invited paper).

Progress Report

For the Transboundary Aquifer Assessment Program (TAAP) during 2017, the team worked with TAAP partners in compiling a draft of the *Binational Study of the Transboundary Santa Cruz Aquifer*, which is undergoing review, and a bilingual summary brochure for the *Binational Study of the Transboundary San Pedro Aquifer* (https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/TAAP-bulletin-2017.pdf).

Under the leadership of UA Professor Christopher Castro, team members contributed to high-resolution regional climate projections for the Santa Cruz River Binational Basin and completed a survey of existing hydrologic models for the Santa Cruz River Aquifer in Mexico to explore the feasibility of using the modeling framework created for the Arizona side of the Santa Cruz River Aquifer to analyze possible impacts of climate uncertainties. The team also started assessing the implications of variabilities of climate and effluent discharges on groundwater recharge downstream of the Nogales International Wastewater Treatment Plant in the Santa Cruz Aquifer.

WRRC TAAP team members also published articles and gave presentations to disseminate TAAP research findings and publicize the program. Presentation venues included regional, national, and international meetings and conferences, including the World Water Congress in Cancun, Mexico, and the Comisión Sonora-Arizona & Arizona-Mexico Commission Annual Meeting in Puerto Peñasco, Sonora. The team engaged stakeholders from the U.S. and Mexico through a workshop held in Sierra Vista, Arizona in June 2017 and a brown bag seminar in February 2018. Megdal's column in the Summer 2017 issue of the Arizona Water Resource discussed the TAAP Cooperative Framework document and its applicability for other transboundary studies. Petersen-Perlman and Megdal wrote an invited chapter on transboundary aquifer assessment, and WRRC team members are coauthors on an invited article for a special issue of the *Journal of Hydrology: Regional Studies* on transboundary aquifer research. The team looks forward to a continuation of binational cooperation with TAAP partners at USGS, the International Boundary and Water Commission, the University of Sonora, CONAGUA, New Mexico State University, and Texas A&M University.

Information Transfer Program Introduction

In 2017, the University of Arizona WRRC's Information Transfer program included two newsletters: a weekly email digest and a quarterly newsletter. The newsletters are distributed by email through Constant Contact. The annual Arroyo publication, which each year covers a different single topic of concern to the water community in Arizona, is provided in both print and digital form. The WRRC hosted its Information Transfer program signature events, including an annual conference and Brown Bag seminar series, along with other special events. In addition, the WRRC website was regularly refreshed with news, events, publications, and program updates. An innovative public water awareness campaign won two prizes for design and topical coverage, and WRRC IT and graphics expertise supported several research and engagement programs. Outreach on social media grew in its role of keeping the WRRC's subscribers and friends informed in a timely manner on items of interest to water community.

Water Resources Research Center

Basic Information

Title:	Water Resources Research Center
Project Number:	2017AZ581B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	AZ-003
Research Category:	Not Applicable
Focus Categories:	None, None, None
Descriptors:	None
Principal Investigators:	Sharon B. Megdal, Susanna Eden, Jean E.T. McLain

Publications

1. Diaz, K.S.; V.I. Rich; J.E. McLain, 2017, Searching for antibiotic resistance genes in a pristine arctic wetland, Journal of Contemporary Water Research and Education, Volume 160, pp. 40-53.
2. Hullinger, A.; K.E. Mott Lacroix; S.B. Megdal, 2017, Conserve2Enhance: Helping Communities Take Action for Water and the Environment, The Solutions Journal, Volume 8 Issue 2. Available at: https://www.thesolutionsjournal.com/article/conserve2enhance-helping-communities-take-action-water-enviro
3. Joe, V.M.; C.M. Rock; J.E. McLain, 2017, Compost tea 101: What every organic gardener should know, Arizona Cooperative Extension Publication.
4. Lacroix, K.E.; E. Tapia; A. Springer, 2017, Environmental flows in the desert rivers of the United States and Mexico: Synthesis of available data and gap analysis, Journal of Arid Environments, Volume 140, pp. 67-78. Available at: http://dx.doi.org/10.1016/j.jaridenv.2017.01.011 and https://authors.elsevier.com/a/1UX24Vu7-iGNc
5. McLain, J.E.; C. Gerba; and C.M. Rock, In Press, Environmental antibiotic resistance associated with land application of biosolids, Antimicrobial Resistance in Wastewater Treatment Processes, Keen, P., R. Fugére (Eds.) Wiley-Blackwell, Hoboken, N.J., USA.
6. Megdal, S.B., 2017, Book Review, Groundwater, Volume 55 Issue 5, pp. 701-702. Available at: http://onlinelibrary.wiley.com/doi/10.1111/gwat.12572/full
7. Megdal, S.B., 2017, Bridging Through Water, Arizona Water Resource, Volume 25 Issue 1, pp. 12-13. Available at: https://wrrc.arizona.edu/bridging-through-water
8. Megdal, S.B., 2017, A Spring Full of Productive Activity!, Arizona Water Resource, Volume 25 Issue 2, pp. 11-12. Available at: https://wrrc.arizona.edu/public-policy-spring-full-productive-activity
9. Megdal, S.B.; S. Eden; E. Shamir, 2017, Water Governance, Stakeholder Engagement, and Sustainable Water Resources Management, Editorial paper for Special Issue of the Same Title, Water, Volume 9 Issue 3, pp. 190-197.
10. Megdal, S.B.; S. Eden; E. Shamir, 2017, Water Governance, Stakeholder Engagement, and Sustainable Water Resources Management, MDPI, Basil, Switzerland, Special Issue Book.
11. Megdal, S.B.; A.K. Gerlak; L.Y. Huang; N. Delano; G. Varady; J.D. Petersen-Perlman, 2017, Innovative Approaches to Collaborative Groundwater Governance in the United States: Case Studies from Three High-growth Regions in the Sun Belt, Environmental Management, Volume 59 Issue 5, pp. 718-735. Available at: http://link.springer.com/article/10.1007/s00267-017-0830-7
12. Neyestani, M.; E. Dickenson; J.E. McLain; C.M. Rock; D. Gerrity, 2017, Solids retention time and antibiotic concentrations as selective pressures for the proliferation of antibiotic resistance during

wastewater treatment, Environmental Science: Water Research and Technology, Volume 3, pp. 883-896.

13. Neyestani, M.; E. Dickenson; J.E. McLain; E. Robleto; C.M. Rock; D. Gerrity, 2017, Impact of solids retention time on trace organic compound attenuation and bacterial resistance to trimethoprim and sulfamethoxazole, Chemosphere, Volume 182, pp. 149 158.
14. Silber-Coats, N.; S. Eden, 2017, Arizona Water Banking, Recharge, and Recovery, Arroyo, Water Resources Research Center, University of Arizona, Tucson, AZ, 16 pg.
15. Weinkam, G.; E. Tapia; S. Eden; A. Springer, 2017, Desert Flows Methodology Guidebook, Determining and Establishing Water Flows for Riparian Ecosystems in the Deserts of the U.S. and Mexico, Water Resources Research Center, University of Arizona, Tucson, Arizona, 40 pg. Available at: https://wrrc.arizona.edu/publications/guide-books/desert-flows-methodology-guidebook

Information Transfer Project

Between March 1, 2017 and February 28, 2018, the WRRC's Information Transfer Program used a variety of established programs and new initiatives to convey water resources information to a range of audiences in Arizona and beyond. Continuing components of the Information Transfer Program include the Annual Conference, the Brown Bag seminar series, electronic and print publications, a dynamic website and frequent communications through email and social media. In addition, the Information Transfer Program assisted research and engagement projects with websites, documents, other outreach materials. The WRRC in continued to promote the multi-faceted project, "Beyond the Mirage", using video, the internet, social media, broadcast television, and face-to-face interactions to raise water consciousness in Arizona and throughout the country. Work carried out during the reporting period is described below.

Annual Conference

Irrigated Agriculture in Arizona: A Fresh Perspective, the WRRC's 2017 Annual Conference, held on March 28th at the UA Student Union Memorial Center in Tucson, presented a broad range of perspectives on Arizona's agricultural water use. The conference was organized in partnership with the Agribusiness & Water Council of Arizona and BKW Farms. The more than 350 people who attended came from 40 Arizona communities, eight other states and Washington DC, five Arizona tribal communities, and Mexico. They were treated to talks and panel discussions from a full roster of 29 irrigators and other agricultural experts. The conference opened with the screening of the documentary, Groundwater: to enact a law for the common good, which recounts the making of Arizona's 1980 Groundwater Management Act. The filmmakers were on hand for a discussion of the need for water leadership. Keynote speakers included Noel Gollehon, Senior Economist with the USDA Natural Resources Conservation Service, Keisha Tatem, Arizona State Conservationist for NRCS, and Clint Chandler, Assistant Director, Water Planning and Permitting Division, Arizona Department of Water Resources. The luncheon program featured Jonathan Mabry, Historic Preservation Officer & Archaeologist for the City of Tucson, who was instrumental in bringing the UNESCO City of Gastronomy designation to Tucson. He talked about Tucson's long and rich history of irrigated agriculture and food traditions. A poster session after lunch provided an opportunity for conferences goers learn about ongoing research and programs. Three students were awarded cash prizes for their posters. One of the many conference sponsors, Southern Arizona Water Users Association, provided funding for the student awards. Other external sponsors included the Arizona Farm Bureau, Water Asset Management, Salt River Project, WestLand Resources, NETAFIM, Arizona Municipal Power Users Association, Arizona Public Service, ADS, Central Arizona Project, Pima County Water Augmentation Authority, EPCOR, Colorado River Indian Tribes, Environmental Defense Fund, Farmers Investment Company, U.S. Bureau of Reclamation, and Montgomery & Associates.

Planning for the 2018 Annual Conference began in the summer of 2017. The conference, “The Business of Water,” was scheduled to take place on Wednesday, March 28, at the UA Student Union Memorial Center. A committee of advisors was assembled with knowledge and expertise at the intersection of water and business. Meetings in person and by telephone established the title, themes and a roster of potential speakers, who were invited to present on specific topics, including selling, leasing, and exchanging water; paying for water infrastructure; water as an economic engine; corporate water stewardship; partnerships for conserving, preserving, and restoring water-dependent ecosystems; and the ethics of water transactions. Preparation for the conference was nearing completion by the end of the reporting period.

Brown Bag Seminars

During the reporting period, the WRRC presented 23 Brown Bag seminars by speakers who covered a range of water resource-related topics chosen to be interesting to a broad spectrum of audiences. Average in-person attendance was 25 and an average of 19 attended through Go-To-Webinar. In-person audiences were made up of about half from the UA Campus and half from the wider community. Go-To-Webinar recordings of most of the Brown Bag seminars can be viewed by going to the WRRC website. Slide presentations from the seminars are also accessible from the website.

Brown Bag seminars from the reporting period are listed below:

January 19, 2017, Tim Thomure, Director, Tucson Water, “Agua Dulce”

February 24, 2017, Grant Davis, General Manager, Sonoma County Water Agency, “Implementing California’s Sustainable Groundwater Management Act and Other Innovative Water Solutions”

March 8, 2017, Merri Lisa Trujillo, Film Producer/Director, "Written on Water"

April 7, 2017, Alexandra Campbell-Ferrari, Executive Director, The Center for Water Security and Cooperation, “Getting to Water Security”

April 13, 2017, Adam Hutchinson, Recharge Planning Manager at Orange County Water District, “Transforming Wastewater to Drinking Water: How Two Agencies Collaborated to Build the World’s Largest Indirect Potable Reuse Project”

April 19, 2017, Candice Rupprecht, Tucson Water and Mary Allen, Pima County Waste Water Reclamation, “The Financial Benefits of Water Conservation: The Tucson Story”

April 26, 2017, Ian Pepper, Professor, Co-Director, WEST Center, “Plugging into WEST: Researchers, Industry, and Arizonans Benefit by Connecting with the UA Water and Energy Sustainable Technology Center”

May 8, 2017, Kelly Mott Lacroix, Ph.D., Hydrologist, U.S. Forest Service, “The Role of National Forest Lands in Improving Watershed Health through the Watershed Condition Framework”

June 16, 2017, Doron Markel, Israeli Water Authority, “Preserving Lake Kinneret (the Sea of Galilee) as a Strategic Regional Water Resource in a Changing Climate”

August 29, 2017, Mark Apel, Area Extension Agent, University of Arizona Cooperative Extension, “Sustainability in the High Atlas Mountains of Morocco – Facing the Impacts of Climate Change”

September 18, 2017, Jessica Asbill-Case, Water Resources Program Manager, Bureau of Reclamation, “Grants Offered by Reclamation through the WaterSMART Program”

October 2, 2017, Clive Lipchin, Arava Institute, “TransBasin—Transboundary Water Basin Management Project”

October 9, 2017, Dave Wegner, Senior Scientific Consultant, Jacobs Engineering, “Adaptive Management in Water Resources”

October 17, 2017, Paul Brierley, Executive Director, Yuma Center of Excellence for Desert Agriculture, “Yuma Agriculture and the Yuma Center of Excellence for Desert Agriculture”

October 25, 2017, Lisa Atkins, Arizona State Land Commissioner, “State Land 101”

November 14, 2017, Andrew Craddock, Analyst, Water Supply Program, Central Arizona Groundwater Replenishment District, “YMIDD/CAGRD Pilot Rotational Fallowing Program, Good for Business, Good Water Management”

December 6, 2017, Meghan Smart, Environmental Scientist, Arizona Department of Environmental Quality, “Camo, Hose Clamps, and Pixels: Arizona’s Approach for Low-cost Intermittent Stream Monitoring”

January 17, 2018, George Frisvold, Professor and Extension Specialist, Department of Agricultural and Resource Economics, University of Arizona “Agriculture in Arizona's Economy: The Role of Modeling and Implications for Water Management”

January 25, 2018, Brian Biesemeyer, Scottsdale Water Director, “Scottsdale Water Campus – 20 Years of Sustainable Water Management”

February 6, 2018, Maria Dadgar, Executive Director, Inter Tribal Council of Arizona, “The Inter Tribal Council of Arizona: Addressing Water and Natural Resource Issues in Arizona”

February 12, 2018, Martin Ralph, Director, Center for Western Weather and Water Extremes and Researcher at UC San Diego's Scripps Institution of Oceanography, "Recent Developments in Atmospheric River Science, Predictions and Applications"

February 21, 2018, Jacob Petersen-Perlman, Research Analyst, Water Resources Research Center, University of Arizona, James Callegary, Hydrologist, USGS Arizona Water Sciences Center, and Elia Tapia, Graduate Research Assistant, Water Resources Research Center, University of Arizona, "Binational Studies of the Transboundary San Pedro and Santa Cruz Aquifers: Results and Future Directions"

February 22, 2018, John Fleck, Director, University of New Mexico Water Resources Program, "How Myths and Misinformation Stand in the Way of Solving our Water Problems"

Co-Sponsored Outreach Events

March 17, 2017, the WRRC convened a roundtable of 40 interested parties on the subject of how much credit should be awarded for managed recharge (effluent discharged to a permitted recharge project within a stream channel) in Arizona. Discussants included Tim Thomure, Director, Tucson Water; Sharon Megdal, Director, WRRC; and Kathy Jacobs, Director, UA Center for Climate Adaptation Science and Solutions.

March 20, 2017, the WRRC joined the Center for Middle Eastern Studies, Arizona Center for Judaic Studies, and Udall Center for Studies in Public Policy to sponsor the screening of "Voice of the Valley," followed by a panel discussion, "Water Issues in the Jordan Valley and Beyond" with Sharon Megdal, WRRC Director; Ramzi Touchan, Professor of Dendrochronology; Gökçe Günel, Assistant Professor, Anthropology and Climate Change.

April 21st, 2017, the WRRC co-sponsored a film screening and panel discussion of "Paya: The Water Story of the Paiute." Discussants included individuals from the Bishop, Big Pine, and Lone Pine Paiute tribes of the Owens Valley: Harry Williams (Environmental Activist), Kathy Bancroft (Tribal Historic Preservation Officer), and Teri Red Owl (Owens Valley Indian Water Commission Director), Jenna Cavelle, filmmaker. Co-sponsors included the UA School of Geography and Development, the Indigenous Peoples Law and Policy (IPLP) program, the Native American Law Student Association (NALSA), and the University of Arizona Environmental Law Society.

September 14, 2017, the School of Natural Resources and Environment hosted the Israeli architect, Liora Meron, co-sponsored by the WRRC.

October 2, 2017, the WRRC co-sponsored a lecture by Clive Lipchin, Director, Center for Transboundary Water Management at the Arava Institute, along with the UA Center for Middle Eastern Studies and Arizona Center for Judaic Studies.

February 16, 2018, the 14th Annual WRRC Chocolate Fest offered chocolate and other treats to WRRC friends and colleagues and showcased the WRRC photo contest winners.

Publications

The **Weekly Wave** is an e-news digest sent to subscribers regularly each week during the academic year and every two weeks during the summer. Each edition includes updates on WRRC and water community events, news, media appearances, announcements, and social media interaction opportunities. During the reporting period, the distribution list grew by approximately 180 recipients to approximately 2,380. Growth in Weekly Wave readership brought increased website traffic, event attendance, and dissemination of WRRC news through other outlets.

The **Arizona Water Resource** (AWR), the WRRC's quarterly newsletter moved to an electronic format in 2017. The number of subscribers increase by more than 300 to approximately 2,200. The electronic version maintains the AWR design and content and can be downloaded from the WRRC website as a PDF. The Summer 2017 AWR include a Special Feature on the 104b research projects funded through the WRRC. Graduate Outreach Assistant R. Andres Sanchez and Undergraduate Student Outreach Assistant Sam Potteiger contributed significantly to developing articles for the AWR. Other student contributors included graduate students Jake Golden and Bailey Kennet, Water, Society and Policy Program, and Anthony Batchelder, Department of Agricultural Economics. In addition, the Student Spotlight feature provided an opportunity to introduce on some of the WRRC's exceptional students. In addition, articles were invited from external authors, including stories following up presentations made at the 2017 Annual Conference, Irrigated Agriculture in Arizona: A Fresh Perspective. A Guest View by Paul Brierley, Executive Director, Yuma Center of Excellence for Desert Agriculture, titled "Shouldn't Ag Water Conservation Be Used For… Agriculture?" carried on a conference discussion. The winners of the WRRC photo contest were featured in the Winter 2018 issue. In addition to brief news articles and items on new resources, each issue of AWR carried the regular Public Policy Review column by WRRC Director Sharon B. Megdal.

The 2017 *Arroyo*, WRRC's annual publication that presents a single topic of timely interest to Arizona in clear and concise language for the interested public, was published in the May. This 16-page publication discussed the various issues relating to Arizona's water banking, recharge, and recovery. It covered groundwater management and the legal framework for recharge, Arizona's recharge projects, the institutions for groundwater banking and replenishment, and recovering stored groundwater. Drafted by Noah Silber-Coats, the 2016 Summer Writing Intern at the WRRC, the 2017 Arroyo was reviewed both internally and externally by experts and knowledgeable agency personnel. Reviewers included Gerry Walker, Kenneth Slowinski and Michelle Moreno, Arizona Department of Water Resources; Warren Tenney, Brett Fleck and Brian Payne, Arizona Municipal Water Users Association; Virginia O'Connell, Arizona Water Banking Authority; William Garfield, Arizona Water Company; Karen Dotson, BKW Farms, Dennis Rule, Central Arizona Groundwater Replenishment District; Kenneth Seasholes, Central Arizona Project; Patricia Jordan, Town of Gilbert; Cynthia Campbell, City of Phoenix; Joe Singleton, Pinal County Water Augmentation Authority; Wallace Wilson, Tucson Water. Printing and mailing was sponsored by the Central Arizona Project.

Work began on the 2018 *Arroyo*, Water and Irrigated Agriculture in Arizona, after the selection in April of the 2017 summer intern, Tim Lahmers, a graduate student in the Department of Hydrology and Atmospheric Science. Lahmers steeped himself in the subject, with the help of video recording from the WRRC's 2017 conference and other research, and produced the first draft of the *Arroyo*. Scheduled for publication in Spring 2018, the *Arroyo* was sent in draft form to a roster of experts for review in February. The Summer Internship and the printing and mailing were funded through donations by the Agribusiness and Water Council of Arizona and BKW Farms.

Website and Electronic Communications

The WRRC website continued to feature news, events, and programs, as well as publications and other resources. The site provided Brown Bag webinar recordings along with access to a searchable video gallery (wrrc.arizona.edu/video-gallery). Updated consistently to keep content fresh, the website had 128,945 page views, a 23 percent increase from the previous year. Of these 94,572 were unique page views, an increase of 14 percent. Website users numbered 50,339, which is also 14 percent higher than the 2016-2017 project year.

The audience for WRRC communications expanded in 2017. In addition to the Weekly Wave, Constant Contact emails advertise events, publications, and other items of interest to our growing lists of recipients. Such items provide posts to keep an active presence of water related news on Facebook, Twitter, and YouTube, resulting in increased shares, views, retweets, follows, and likes. Externally, the WRRC, its projects and personnel, have been featured 44 times across a variety of news and media outlets.

Program Collaborations

The WRRC extends its research, outreach, and education role through its collaborations. Collaborative activities with the Water, Environmental and Energy Solutions (WEES) initiative have included co-sponsoring lecturers and other events and disseminating information to the more than 300 UA investigators involved in water-related research. Since July 2016 the WRRC Director has served the WEES Director. Collaborations with the WRRC-based Arizona Project WET (Water Education for Teachers) have expanded the reach and effectiveness of outreach and education projects of both partners, and this collaborative relationship continued through the project year. A comprehensive water education program with growing relationships with school districts and communities throughout the state, Arizona Project WET provides programs, workshops, mentoring, and partnership activities for teachers, students, and community members.

Ongoing programs of research and outreach continued and were expanded. The Transboundary Aquifer Assessment Program (TAAP) in Arizona focuses on two U.S.-Mexico shared aquifers for studies by researchers on both sides of the border to increase the information available for groundwater management. The goal of Water Research and Planning Innovations for Dryland Systems (Water RAPIDS) is to help balance water demand for human uses with the water demands of ecosystems. Other WRRC programs include the Water Quality Research Lab, Desert Water Harvesting Initiative, Conserve2Enhance, Groundwater Governance and Management, and Middle East Water. Outreach is a major function of many WRRC research projects, and although they are almost entirely funded from other sources, their outreach receives some support from the Information Transfer Program.

Beyond the Mirage

Multiple screenings of the "Beyond the Mirage" documentary for specific audiences took place in 2017. The documentary, which was broadcast on public television stations, received a Rocky Mountain Emmy for Best Topical Documentary, and the documentary and interactive experience won an American In-house Design Award from Graphic Design USA.

Other Activities

In addition to all of the above, WRRC personnel were called upon regularly to give lectures and make presentations to diverse audiences across Arizona. They collaborated with local, state, regional, and federal agencies and organizations, as a resource for general water resource related information and as partners on specific projects. WRRC personnel participated on community and regional boards and commissions, and served on state and local task forces and study committees. The WRRC facility is open to the public and continues to provide informational materials on water-related topics to the public and a space for water-related meetings. WRRC personnel also responded to inquiries from the public on issues of concern.

Presentations

Presentations for Information Transfer on 104b and Supplemental projects

Project Number: 2015AZ540B

Title: Water Sources Over Time for a Semi-Arid River: Implications for water resources and groundwater modeling

Stolar, Rebecca, Populus fremontii Tree-Ring Analysis and Semi-Arid River Water Source Variability Over Time, San Pedro River, Arizona, Presentation at El Dia Del Agua y la Atmosfera, Department of Hydrology and Atmospheric Sciences, Tucson AZ, University of Arizona April 9,2018.

Project Number: 2017AZ570B

Title: Impact of Projected Climate Changes on Mountain-Block Recharge Processes

Dwivedi, R., T. Meixner, J. McIntosh, P. A. T. Ferré, G.-Y. Niu, and J. Chorover (2017), Characterization of water sources and flowpaths and their influence on groundwater geochemical evolution and mineral weathering rates in a high elevation mountain catchment, in *Critical Zone Science: Current advances and future opportunities*, edited, Arlington, VA.

Ravindra Dwivedi, Thomas Meixner, Jennifer C. McIntosh, P. A. "Ty" Ferré, Christopher J. Eastoe, Rebecca L. Minor, Greg A. Barron-Gafford, and Jon Chorover, Hydrologic functioning of the deep Critical Zone and contributions to streamflow in a high elevation catchment: testing of multiple conceptual models (Poster ID: H41C-1449), AGU Fall meeting at New Orleans, LA, December 11-15, 2017.

Ravindra Dwivedi, T. Meixner, J. McIntosh, P. A. "Ty" Ferre, C. Eastoe, C. Castro, G. -Y. Niu, R. Minor, J. Knowles, Greg A. Barron-Gafford, N. Abramson, B. Mitra, M. Stanley, and J. Chorover, Importance of soil and fractured bedrock storage in sustaining vegetation productivity and streamflow for sub-humid mountainous catchments, El Día del Agua y la Atmósfera, University of Arizona, Tucson, AZ, April 9, 2018.

Project Number: 2017AZ576B

Title: Might Recycled Wastewater Solve the Rising Problem of Toxin-Producing Algae?

Lynch, R.A., K. Fitzsimmons, T. Meixner, L. Abrell, and J.E. McLain. Might Recycled Wastewater Solve the Problem of Toxin-Producing Algae? University of Arizona Department of Soil, Water and Environmental Science, SWESx, April 12, 2018.

Lynch, R.A. Might Recycled Wastewater Solve the Problem of Toxin-Producing Algae? Invited lecture, BIO320, Fundamentals of Ecology, Arizona State University Lake Havasu Campus, Lake Havasu City, AZ, April 11, 2018.

Project Number: 2016AZ584S and 2017AZ587S

Title: Transboundary Aquifer Assessment Program (TAAP): Arizona Water Resources Research Center Effort

Petersen-Perlman, J.D. and S.B. Megdal, Efforts Towards Transboundary Groundwater Assessment and Governance: Transboundary Aquifer Assessment Program in Arizona and Sonora, American Association of Geographers Meeting 2017, Boston, MA, April 9, 2017 (presented by Jacob D. Petersen-Perlman).

Megdal, S.B., The Joint Cooperative Framework for the Transboundary Aquifer Assessment Program, Part 2 of three-part Special Session on Shared Waters of North America, World Water Congress XVI, Cancun, Mexico, May 30, 2017.

Tapia-Villaseñor, E.M., J.B. Callegary, I. Minjarez Sosa, R. Monreal Saavedra, F.J. Grijalva Noriega, F. Gray, J.D. Petersen-Perlman, and S.B. Megdal, The Transboundary Aquifer Assessment Program and the Binational Study of the San Pedro Aquifer, World Water Congress, Cancun, Mexico, May 30, 2017 (presented by Elia M. Tapia-Villaseñor).

Petersen-Perlman, J.D. Additional Dialogue on the US-Mexico Transboundary Aquifer Assessment Program: Past, present, and future, Universities Council on Water Resources/National Institutes for Water Resources Annual Conference, Fort Collins, CO. June 14, 2017.

Tapia-Villaseñor, E.M., S.B. Megdal, and J.D. Petersen-Perlman, The U.S. Mexico Transboundary Aquifer Assessment Program in Arizona: Current and future efforts, Universities Council on Water Resources/National Institutes for Water Resources Annual Conference, Fort Collins, CO, June 14, 2017 (presented by Elia M. Tapia-Villaseñor).

Megdal, S.B. Callegary, J., Tapia-Villaseñor, E.M., and J.D. Petersen-Perlman, The Transboundary Aquifer Assessment Program: The Importance of the Joint Cooperative Framework, Sierra Vista workshop on the *Binational Study of the Transboundary San Pedro Aquifer*, Sierra Vista, Arizona, June 20, 2017.

Megdal, S.B., The Cooperative Framework for the U.S.-Mexico Transboundary Aquifer Assessment Program: A Model for Collaborative Transborder Studies, Cutting-Edge Solutions to Wicked Water Problems, Joint Conference of the American Water Resources Association and the Water Research Center at Tel Aviv University, Tel Aviv, Israel, September 10-11, 2017.

Petersen-Perlman, J.D., The Transboundary Aquifer Assessment Program: Assessing Arizona's Shared Groundwater Resources, American Planning Association Arizona State Planning Conference, Fountain Hills, Arizona. October 25, 2017.

Tapia-Villaseñor, E.M., The Arizona/Sonora Transboundary Aquifer Assessment Program: GIS and Mapping, University of Arizona GIS Day, November 15, 2017.

Megdal, S.B., Update on the Transboundary Aquifer Assessment Program, Environment & Water Committee, Arizona-Mexico Commission, Puerto Peñasco, Sonora, MX, November 30, 2017.

Petersen-Perlman, J.D., J. Callegary, and E.M. Tapia-Villaseñor, Binational Studies of the Transboundary San Pedro and Santa Cruz Aquifers: Results and Future Directions, University of Arizona Water Resources Research Center, Brown Bag Seminar, February 21, 2018.

Petersen-Perlman, J.D. and S.B. Megdal, The Transboundary Aquifer Assessment Program – Past, Present, and Future, US-Mexico Border Water Summit. El Paso, Texas, March 1, 2018.

Tapia-Villaseñor, E.M., Implications of Precipitation Uncertainties to the Water Resources in the Transboundary Santa Cruz Basin, US-Mexico Border Water Summit. El Paso, Texas, March 1, 2018.

Presentations by WRRC Personnel

McLain, Jean, Water recycling 101: What every Arizonan should know as we move into our water future. Lecture, Osher Lifelong Learning (OLLI) Institute at the University of Arizona, Green Valley, AZ. March 3, 2017

Megdal, Sharon B., Beyond the Mirage and Water Management in Israel and the Tucson Region. Presentation, Saddlebrooke Israel Friendship Club, Saddlebrooke Community, AZ. March 6, 2017

Megdal, Sharon B., Desalination in Arizona's Water Management Portfolio – An International Perspective. Panelist, ASU Kyl Center Leaders Roundtable Luncheon on the Future of Desalination, Phoenix, AZ. March 10, 2017

McLain, Jean, Current and future water sustainability efforts in the Tucson area. Presentation, Tucson Mountains Association Monthly Board Meeting, Tucson, AZ. March 15, 2017

McLain, Jean, Long-term memories and impact of the Faculty Fellowship to Israel. Presentation, Jewish National Foundation Donors Meeting, Paradise Valley, AZ. March 19-20

Megdal, Sharon B., Panelist, Water in the Jordan Valley (film screening). University of Arizona, Tucson, AZ. March 20

Eden, Susanna, What's "Beyond the Mirage" film screening and Q&A. Lecture, Osher Lifelong Learning Institute at the University of Arizona (OLLI-UA), Green Valley, AZ. March 24, 2017

Eden, Susanna, The Water Resources & Climate Assessment Tool [WARCAT] for the Santa Cruz Active Management Area. Presentation, Santa Cruz River Research Days IX, Tucson, AZ. March 29, 2017

Megdal, Sharon B., Alternatives to Permanent Fallowing of Agricultural Land: What's Feasible for Colorado River Lower Basin States? Presentation, DoubleTree - Reid Park, Tucson, AZ. March 29, 2017

McLain, Jean, EPA-approved methods for identification of E. coli to monitor water quality. Presentation, The Center for Produce Safety Water Monitoring Roundtable, Irvine, CA. April 6, 2017

Petersen-Perlman, Jacob, Hydropolitical Resilience in Transboundary River Basins. Presentation, ENR2 S495, University of Arizona, Tucson, AZ. April 9, 2017

Megdal, Sharon B., Israel's Shared Borders and Shared Waters: Water as a Bridge and a Barrier. Lecture, Arizona Center for Judaic Studies Lecture Series, University of Arizona, Tucson, AZ. April 19, 2017

Megdal, Sharon B., Facilitator, Lower Santa Cruz River Basin Study, meeting of the External Stakeholder Group, Tucson, AZ. April 24, 2017

Megdal, Sharon B., Beyond the Mirage: A Look at Our Region's Water Management Successes and Challenges. Presentation, Tucson Rotary, Tucson, AZ. April 26, 2017

Megdal, Sharon B., Global Freshwater Issues and Desalination. Panelist /Participant, ASU Origins Project: The Coming Water Wars…and how to avoid them, Arizona State University, Tempe, AZ. April 28-29, 2017

Weinkam, Grant, Water RAPIDS Program at the U of A: For a better understanding of the complexity and diversity of water challenges experienced by Arizona communities. Presentation, Arizona Water Association Annual Conference, Phoenix, AZ. May 5, 2017

Megdal, Sharon B., Bridging Through Water – Israel as an Innovator in Water Management and Technology. Presentation, Gertrude and Fred Rosen Memorial Lecture, Weintraub Israel Center and Tucson Jewish Community Center, Tucson, AZ. May 7, 2017

Megdal, Sharon B., International Relevance of Arizona Water Management. Presentation, HDR Arizona Municipal Utilities Leadership Institute Forum, Show Low, AZ. May 11, 2017

Megdal, Sharon B., Groundwater Governance and Management in the U.S., Webinar, American Water Resources Association. May 17, 2017

Megdal, Sharon B., Special Session on the OECD Water Governance Initiative. Panelist, World Water Congress XVI, Cancun, Mexico. May 29, 2017

Megdal, Sharon B., The Joint Cooperative Framework for the Transboundary Aquifer Assessment Program, Part 2 of three-part Special Session on Shared Waters of North America. Presentation, World Water Congress XVI, Cancun, Mexico. May 30, 2017

Megdal, Sharon B., High-level panel on Shared Waters of North America, Part 3 of three-part Special Session on Shared Waters of North America. Panel Moderator, World Water Congress XVI, Cancun, Mexico. May 30, 2017

Megdal, Sharon B., Regular Session 18, Water Policy and Governance. Session Chair and Rapporteur, World Water Congress XVI, Cancun, Mexico. May 31, 2017

Megdal, Sharon B., Groundwater utilization trends by Central Arizona agriculture and results of state groundwater surveys. Presentation, UCOWR Annual Conference, Ft. Collins, CO. June 13, 2017

Megdal, Sharon B., Opening plenary session. Moderator, UCOWR Annual Conference, Ft. Collins, CO. June 13, 2017

Megdal, Sharon B., Challenges and Opportunities Associated with Two Graduate Interdisciplinary Program at the University of Arizona. Presentation, UCOWR Annual Conference, Ft. Collins, CO. June 14, 2017

Megdal, Sharon B., Challenges of Interdisciplinary Graduate and Undergraduate Programs in Water Resources. Presentation, UCOWR Annual Conference, Ft. Collins, CO. June 14, 2017

Megdal, Sharon B., Luncheon plenary session. Moderator, UCOWR Annual Conference, Ft. Collins, CO. June 14, 2017

Petersen-Perlman, Jacob, Additional Dialogue on the US-Mexico Transboundary Aquifer Assessment Program: Past, present, and future. Presentation, UCOWR Annual Conference, Ft. Collins, CO. June 14, 2017

McLain, Jean, Mine spills and antibiotic resistance: what is the connection? Presentation, 2nd Annual Conference on Environmental Conditions of the Animas and San Juan Watersheds, with Emphasis on Gold King Mine and Other Mine Waste Issues, Farmington, NM. June 22, 2017

McLain, Jean, Identification of acute hepatopancreatic necrosis disease (AHPND) in black tiger shrimp (Penaeua monodon), Pacific white shrimp (Penaeus vannamei), and fresh water shrimp (Macrobrachium rosenbergii). Presentation, World Aquaculture Society APA 17, Kuala Lumpur, Malaysia. July 25, 2017

Megdal, Sharon B., Everyone is a Water Stakeholder: A Call for Water Stewardship. Presentation, First National Leadership Women Conference, Dallas, TX. July 28, 2017

Megdal, Sharon B., Beyond the Mirage. Screening and Discussion, hosted by the U.S. Bureau of Reclamation, Pacific Beach Public Library, San Diego, CA. August 1, 2017

McLain, Jean, How to construct an effective presentation: it's not as hard as you think. Lecture, ENVS696a: Topics in Soil, Water and Environmental Science, University of Arizona, Tucson, AZ. August 30, 2017

McLain, Jean, Agricultural Reuse. Session Moderator, University of Arizona, Tucson, AZ. September 10, 2017

Megdal, Sharon B., Beyond the Mirage. Screening and discussion moderator, Joint Conference of the American Water Resources Association and The Water Research Center at Tel Aviv University, Tel Aviv, Israel. September 10, 2017

Megdal, Sharon B., Reuse of Grey Water for Non-domestic Uses in Jordan. Presentation, American Water Resources Association and Water Research Center Tel Aviv University, 2017 International Conference: Cutting-Edge Solutions to Wicked Water Problems, Tel Aviv, Israel. September 11, 2017

Megdal, Sharon B., The Cooperative Framework for the U.S.-Mexico Transboundary Aquifer Assessment Program: A Model for Collaborative Transborder Studies. Presentation, American Water Resources Association and Water Research Center Tel Aviv University, 2017 International Conference: Cutting-Edge Solutions to Wicked Water Problems, Tel Aviv, Israel. September 11, 2017

Megdal, Sharon B., Plenary Moderator for Opening and Closing Plenary Sessions, American Water Resources Association and Water Research Center Tel Aviv University, 2017 International Conference: Cutting-Edge Solutions to Wicked Water Problems, Tel Aviv, Israel. September 11, 2017

Petersen-Perlman, Jacob, Subsidiarity in International Water Resources Cooperation: A Path Forward? Presentation, American Water Resources Association and Water Research Center Tel Aviv University, 2017 International Conference: Cutting-Edge Solutions to Wicked Water Problems, Tel Aviv, Israel. September 11, 2017

Eden, Susanna, Water Harvesting Assessment Toolbox: Project, Product, and Lessons Learned. Presentation, 14th Biennial Conference of Science & Management on the Colorado Plateau & Southwest Region, Flagstaff, AZ. September 12, 2017

McLain, Jean, Teaching harvested rainwater microbiology in Arizona communities: lessons learned. Presentation, 14th Biennial Conference of Science and Management on the Colorado Plateau and Southwest Region, Flagstaff, AZ. September 12, 2017

Megdal, Sharon B., From scarcity to abundance: New perceptions about water value. Panelist, WATEC 2017, Tel Aviv, Israel. September 12, 2017

Eden, Susanna, Water Harvesting Basics. Presentation, Cooperative Extension Water Resources Information Workshop, Miami, AZ. September 24, 2017

Hullinger, Ashley and Susanna Eden, Water Resources Assessment Report for Cobre Valley, AZ. Presentation, Cooperative Extension Water Resources Information Workshop, Miami, AZ. September 24, 2017

Hullinger, Ashley and Susanna Eden, Water Resources Assessment Report for Cobre Valley, AZ. Presentation, Miami Town Council Meeting, Miami, AZ. September 25, 2017

Petersen-Perlman, Jacob, State-Level Groundwater Governance and Management in the United States: Results of a survey funded by the Ground Water Research and Education Foundation (GWREF). Presentation, 2017 Ground Water Protection Council Annual Meeting, Boston, MA. September 29, 2017

McLain, Jean, Are we spreading antibiotic resistance in the environment with recycled wastewater? Separating the knowns from the unknowns. Presentation, WEFTEC (Water Environment Federation Annual Conference), Chicago, IL. October 2, 2017

Petersen-Perlman, Jacob, Groundwater Quality Management and Governance at the State Level. Webinar, National Ground Water Association. October 19, 2017

Megdal, Sharon B., Wicked Water Problems and the International Relevance of Arizona Water Management. Presentation, Southern Arizona Water Users Association (SAWUA) Water Issues in Southern Arizona forum, Tucson, AZ. October 20, 2017

Petersen-Perlman, Jacob, The Transboundary Aquifer Assessment Program - Assessing Arizona's Shared Groundwater Resources. Presentation, Arizona Planning Association Meeting, Fort McDowell, AZ. October 25, 2017

Megdal, Sharon B., Perspectives on Water Scarcity and Abundance. Presentation, Lightning Plenary Session, American Water Resources Association Annual Conference, Portland, OR. November 6, 2017

Megdal, Sharon B., Developing meaningful partnerships at home and abroad: The importance of networking, communicating, and volunteering. Presentation, American Water Resources Association Annual Conference, Portland, OR. November 8, 2017

Megdal, Sharon B., Update on the Transboundary Aquifer Assessment Program. Presentation, Environment & Water Committee, Arizona-Mexico Commission, Puerto Peñasco, Sonora, Mexico. November 30, 2017

Megdal, Sharon B., Water as a Bridge and a Barrier to Resolving Israeli-Palestinian Conflicts. Presentation, Harvard Club of Tucson, AZ. December 10, 2017

Petersen-Perlman, Jacob, Hydropolitical Resilience and Scale in Transboundary River Basins. Lecture, ENR2 S445, University of Arizona, Tucson. January 18, 2018

Eden, Susanna, Water for Arizona’s Desert Communities: Sources, Uses & Management. Presentation, Voyager RV Resort, Tucson, AZ. January 11, 2018

Petersen-Perlman, Jacob, Water Sharing across Borders: Water Issues in the Colorado, Santa Cruz, and San Pedro Basins. Lecture, Osher Lifelong Learning (OLLI) Institute at the University of Arizona, Green Valley, AZ. January 24, 2018

Eden, Susanna, Agricultural Water Use in Arizona. Lecture, Lecture, Osher Lifelong Learning (OLLI) Institute at the University of Arizona, Green Valley, AZ. January 31, 2018

Petersen-Perlman, Jacob, Transboundary Groundwater Governance and Management: International Governance and Sustainability. Lecture, McMaster University, Hamilton, Ontario, Canada (delivered via Skype). February 15, 2018

Megdal, Sharon B., Desalination in Israel. Presentation, Multi-State Salinity Coalition (MSCC) 2018 Annual Salinity Summit, Las Vegas, NV. February 8, 2018

Megdal, Sharon B., UCOWR/NIWR partnership. Presentation, National Institutes for Water Resources Annual Meeting, Washington, DC. February 26, 2018

Megdal, Sharon B., The Transboundary Aquifer Assessment Program (TAAP): A Cooperative Effort of the United States and Mexico. Presentation, Global Environmental Facility with discussant from the World Bank, Washington, DC. February 28, 2018

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	1	0	0	0	1
Ph.D.	1	0	0	1	2
Post-Doc.	0	0	0	0	0
Total	3	0	0	1	4

Notable Awards and Achievements

Graduate student Ravindra Dwivedi received a Horton Research Grant in 2017 from the American Geophysical Union.

Graduate student Robert Lynch won an award for best graduate student oral presentation by a graduate student at the University of Arizona Department of Soil, Water and Environmental Science, SWESx Celebration of Earth Day, April 12, 2018.

PI Robert Lynch and Prof. Jean McLain were filmed collecting samples and answering interview questions at the Sweetwater Wetland for a film highlighting cutting-edge research performed by graduate students in the Department of Soil, Water and Environmental Science, which will be posted on the SWES website and used in informing potential students.

the Idaho Department of Environmental Quality requested information on the results of the project "Might Recycled Wastewater Solve the Problem of Toxin-Producing Algae?"

The documentary, Beyond the Mirage, on which the WRRC collaborated, was broadcast on public television stations and received a Rocky Mountain Emmy for Best Topical Documentary. The documentary and interactive experience won an American In-house Design Award from Graphic Design USA.

The Transboundary Aquifer Assessment Program completed the Binational Study of the Transboundary San Pedro Aquifer, which was officially approved by the U.S. and Mexican sections of the International Boundary and Water Commission. This first-ever binational aquifer assessment report was prepared simultaneously in English and Spanish.

Publications from Prior Years

1. 2016AZ552B ("Sunlight-driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds") - Articles in Refereed Scientific Journals - Cheng, L., T. Zhang, H. Vo, D. Diaz, D. Quanrud, R.G. Arnold, A.E. Sáez, Effectiveness of Engineered and Natural Wastewater Treatment Processes for Water Reuse, Journal of Environmental Engineering, 143, 1-18 (2017)
2. 2016AZ552B ("Sunlight-driven reactive oxygen species production for natural attenuation of wastewater trace organic compounds") - Dissertations - Vo, Hao, Transformation of Trace Organic Contaminants Involving Reactive Oxygen Species Driven by Solar Light, PhD Dissertation, Department of Chemical and Environmental Engineering, November 2017.
3. 2016AZ584S ("Transboundary Aquifer Assessment Program (TAAP): Arizona Water Resources Research Center Effort") - Dissertations - Zhang, Tianqi, Modeling Photolytic Advanced Oxidation Processes for the Removal of Trace Organic Contaminants, PhD Dissertation, Department of Chemical and Environmental Engineering, April 2017.